Broadband twin tail fins antenna on HR SOI silicon substrate for 60GHz applications

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Broadband Twin Tail Fins Antenna on HR SOI Silicon Substrate for 60 GHz Applications

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***Abstract*—This paper presents a broadband antenna on HR SOI CMOS technology for co-integration with power amplifier (PA) or low noise amplifier (LNA). In a System on Chip (SoC) approach, the co-design of the antenna and Integrated Circuits (ICs) on a same silicon substrate is a convenient solution to suppress lossy matching networks and to reduce the radio front-end cost. The proposed antenna presents a simulated gain greater than 5 dBi and a simulated $|S_{11}|_{dB}$ below -10 dB over a 30 GHz frequency band [53-80 GHz]. This concept has been validated on Alumina substrate with a good agreement between measurement and simulation.**

***Index Terms* — Integrated Antenna, co-design, HR SOI silicon, Millimeter Wave, SoC approach.**

I. Introduction

At mmWave (millimeter wave) frequencies, high data rate applications such as Wireless HDMI or Kiosk downloading require low cost and low power System on Chip (SoC) for addressing mass-market products and expectations. Thanks to the recent progress of Integrated Circuits (ICs) on CMOS or BiCMOS Silicon technologies, the complete integration of the RF front-end on a single chip is now achievable [1]. But mmWave antennas suffer from their integration on lossy silicon substrate. Due to the Low Resistivity (LR) Silicon substrate characteristics (dielectric constant, loss tangent, thickness), integrated antennas exhibit quite low gain and reduced radiating efficiency [2, 3]. Using High Resistivity (HR) Silicon technology as the antenna substrate helps to improve performances thanks to a reduced part of energy previously dissipated in the lossy substrate (when LR Silicon is considered). Besides, a HR SOI CMOS integrated RF front-end, including a silicon integrated antenna, has been demonstrated [4]. So, in order to propose a high performance low cost SoC, a co-integration of the antenna and ICs can be proposed on HR SOI CMOS. The objectives of co-design are to reduce the cost of the radio front-end and to enhance the global system budget efficiency. Indeed, the advantages of the co-integration of the antenna with a PA or a LNA are the suppression of the matching network stage and the direct matching of the antenna to the output – respectively the input – impedance of the PA – respectively the LNA.

To target kiosk-file downloading applications (Usage Model 5 for IEEE-802.15.3c [5]), Line Of Sight (LOS) configuration is considered on a limited distance (< 3 meters). So, for the antenna specifications, a 5 dBi gain is typically required over the 9 GHz band [57-66 GHz].

In this context, we propose a new solution of integrated antenna on HR SOI CMOS technology, which appears as fully compatible with radio front-end environment and respects the standard specifications [6].

This article is organized as follow: Section II describes the elementary antenna design and its performances, with validation measurements on Alumina ceramic substrate in Section III. Section IV details the interest of such structure for co-integration by studying the surface current distribution on the antenna backside. Finally, Section V gives some conclusions and perspectives.

II. Ultra Broadband Twin Tail Fins Antenna

The proposed antenna is built in a standard SOI CMOS technology on a High Resistivity (HR) silicon substrate (εr_{Si} = 11.7; σ_{Si} = 0.001 S/m) with a thickness of one hundred of µm. It can be fed by two types of transmission lines: CPW (CoPlanar Waveguide) and TFMS (Thin Film MicroStrip) which are compatible with HR SOI CMOS silicon technology at millimeter wave frequencies (Fig. 1). Such configurations permit to cover the different PA and LNA expected impedances values. The TFMS is appropriate for low impedance value (around 20 Ω) and the CPW for high impedance value (around 70 Ω).

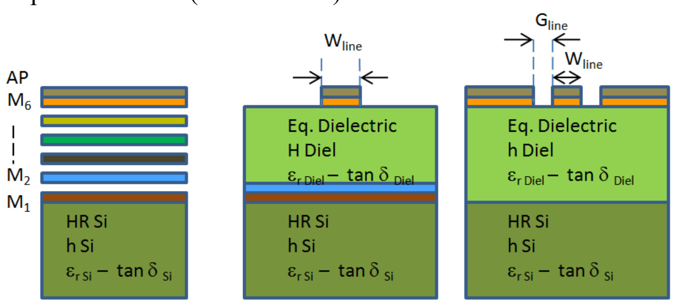
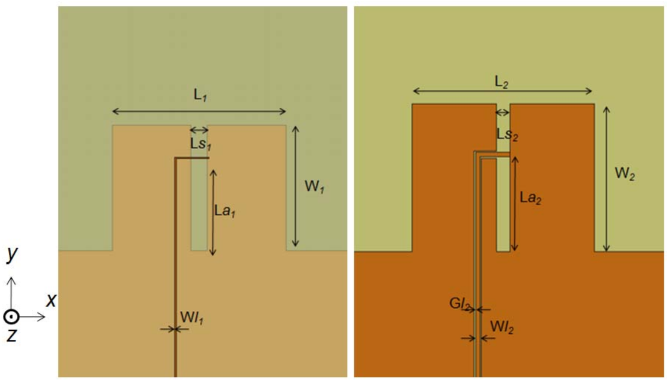


Fig.1 Simplified BEOL (Back End Of Line) of standard HR SOI CMOS STMicroelectronics process used for TFMS and CPW topology.

The proposed antenna is a planar type dipole with a shape ratio allowing bandwidth enhancement and an intrinsic integrated balun. With the TFMS configuration, the transmission line is made on Metal 6 and the antenna is printed on Metal 1 and Metal 2. The extremity of the transmission line is connected to the edge of the other metallization part with a via between Metal 6 and Metal 2. With the CPW configuration, the antenna and the transmission line are both reported on Metal 6. The signal feeding line is inserted in the left so-called "tail fin" of the antenna and short-circuited itself on the other tail fin.

The two configurations present a microstrip or coplanar strip to slotline transition for the differential access ports of the antenna. The short-circuit conditions, realized with either a via (for TFMS) or a direct connection (for CPW), appears a quite a wider broadband configuration than a frequency selective quarter wavelength stub. Consequently, the association of this feeding structure with the antenna shape ratio leads to a broader band antenna.

The antenna is designed using 3D electromagnetic simulation software HFSS™. The different parameters L_n, W_n, Ls_n, La_n Wl_n and Gl_n are optimized for an input impedance of 50 Ω over the expected frequency band (Fig. 2).



(a) (b)

Fig.2 Top view of the antenna with the TFMS configuration (a) and the CPW configuration.

The antenna exhibits a bandwidth (@VSWR = 2) exceeding 30 GHz from 53 GHz to more than 80 GHz for both types of excitation (TFMS and CPW) (Fig. 3).

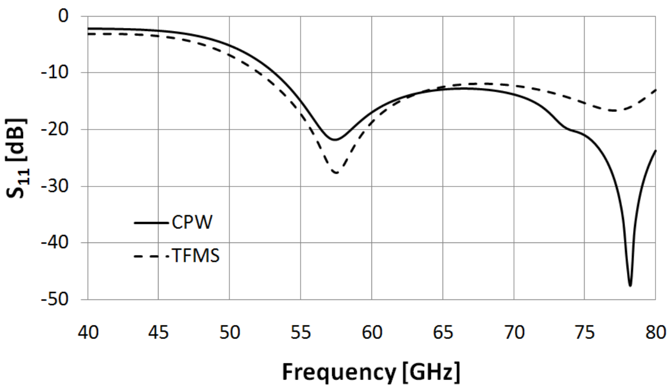
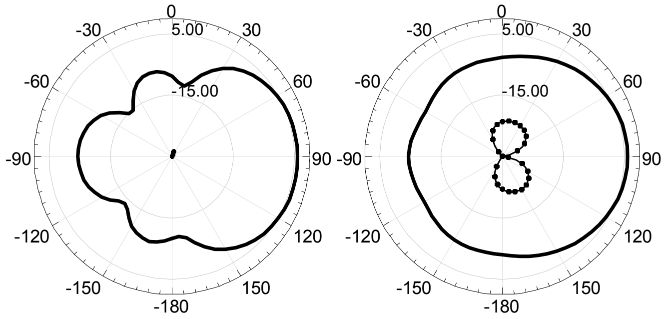


Fig.3 Simulated return loss of the antenna with TFMS and CPW configurations.

The first resonance at 57 GHz is fixed by the L_n parameter which is equivalent to $\lambda_g/2$ like a classical dipole antenna. The second resonance at 77 GHz is due to the form factor of the entire structure which increases the bandwidth specifically at high frequencies.

The simulated radiation patterns of the antenna in the E- and H-planes at 60 GHz are shown on Fig. 4(a) and (b) respectively. The gain in the $+y$ direction ($\theta=\varphi=90°$) is 6.1 dBi and the Front to Back ratio (F/B ratio) is equal to 10 dB. In the E- and H-planes, the co-/cross-polarization ratio values, observed at 60GHz, are particularly high (above 20 dB). With this ratio, the cross-polarization does not disturb the antenna radiation.

The antenna also presents an efficiency of 85%, and a 8 mm² area.



(a) (b)

Fig.4 Radiation pattern of the CPW antenna configuration at 60 GHz: E Plane co/cross-Polarization (a) – H Plane co/cross-Polarization (b).

The simulated gain, shown in Figure 5, is greater than 5 dBi over more than 25 GHz bandwidth for both excitation types. The peak gain observed at 77 GHz is mainly due to the effect of the shielded back ground plane of the antenna which contribution is more significant at this frequency rather than at 57 GHz.

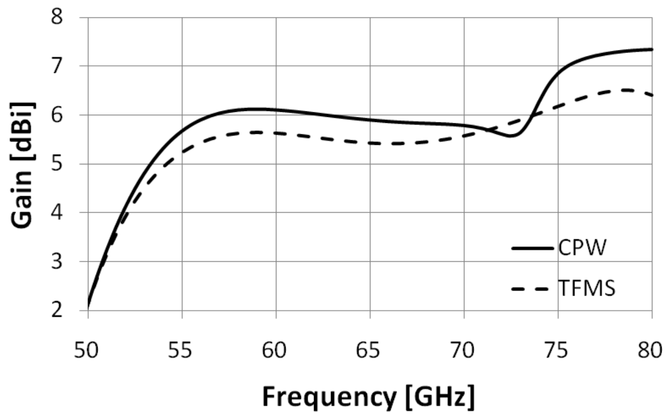


Fig.5 Simulated gain of the antenna with TFMS and CPW configurations.

In Table I, we present the different gain values and co-/cross-polarization ratios at different frequencies for E- and H- planes for the antenna with a CPW feeder. The radiation performances are very constants over the studied frequency band [55-80 GHz]. The co-/cross-polarization ratio in the two antenna planes is very important and permits to obtain a high polarization purity on the entire bandwidth. These results show a good stability on a wide frequency band for this antenna.

TABLE I

RADIATION PERFORMANCES

Frequency [GHz]	Gain [dBi]	Co/Cross ratio in E Plane [dB]	Co/Cross ratio in H Plane [dB]
55	5,66	30,9	21,6
60	6,10	31,5	20,8
65	5,90	30,8	20,0
70	5,80	27,4	20,0
75	6,84	22,8	25,1
80	7,34	27,4	24,3

III. MEASUREMENT

Thus, experimental realizations and tests have been conducted to validate this concept. The antenna is implemented on an alternative substrate: Alumina (εr=9.9 – thickness h=254µm), fitting quite accurately the Silicon support. The antenna has been measured with a probe station at Lab-STICC and on an antenna test bench at STMicroelectronics [7]. The measurement results are shown on Fig. 6 and present a good agreement with simulation. The two test benches have not the same environment and explain the difference between the measurements around 60 GHz. The support of the antenna under test is made of foam (εr=1.1) on Lab-STICC test bench and Rexolite® 1422 (εr=2.53) on STMicroelectronics test bench.

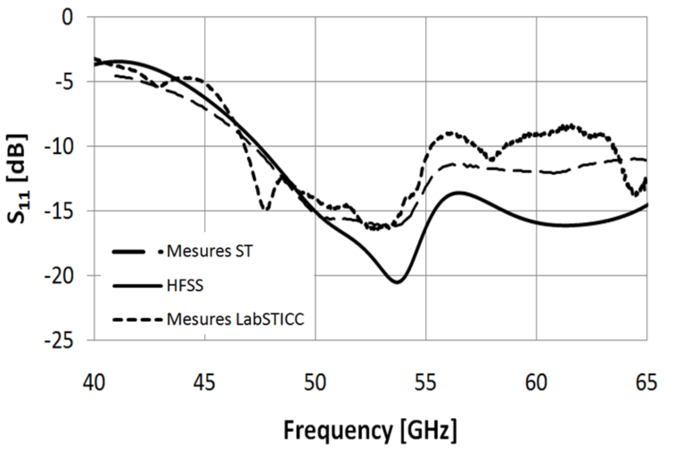


Fig.6 Measured return loss of the antenna with CPW configuration on Alumina.

A link budget is realized between two identical antennas with a distance of 1 cm for measuring the gain in the main radiation axis. The measurement result is presented on Fig. 7. We observe a measured gain of 3.9 dBi over the 45-65 GHz with a gain decrease around 57 GHz. This decrease is essentially due to the antenna design on thick Alumina substrate and further realizations are planned in HR SOI CMOS technology to optimize the gain over the entire bandwidth.

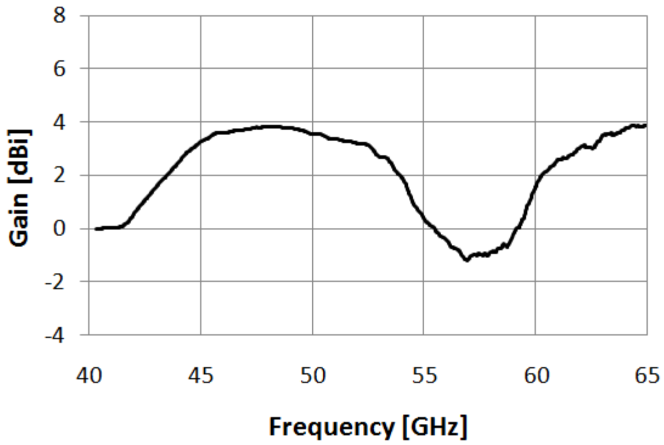
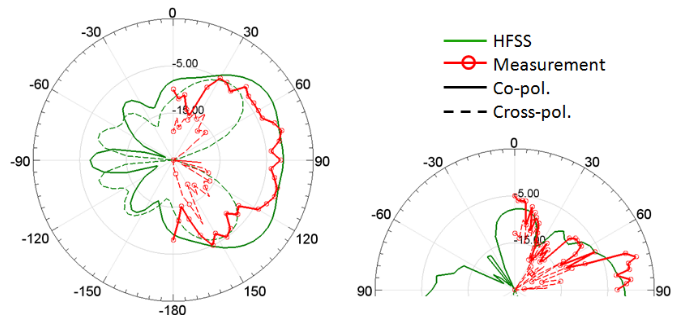


Fig.7 Measured gain of the antenna with CPW configuration on Alumina.

Figure 8 presents the measured radiation pattern of the antenna on Alumina obtained by the STMicroelectronics test bench. The radiation pattern acquired by simulation under HFSS™ takes into account the measurement environment (proximity of the probes and cable) and a good agreement with measurement is observed. As a consequence, the half-power beamwidth in E-plane is smaller. These results show the impact of the environment on the antenna radiation.



(a) (b)

Fig.8 Measured and simulated radiation pattern of the antenna with CPW configuration on Alumina: E-plane (a) H-plane (b).

IV. ANTENNA IN A CO-INTEGRATION ENVIRONMENT

In a co-integration scheme between the antenna and ICs, a good isolation between the different parts is very important for an optimal behavior of each element. In this context, we propose to study the impact of the antenna radiation on the active circuits. In co-design, the active circuits (PA or LNA) are located just behind the antenna (Fig. 9). The visualization of the surface current distribution on metal surfaces is presented on Fig. 10 (a) and (b) at 57 GHz and 77 GHz respectively.

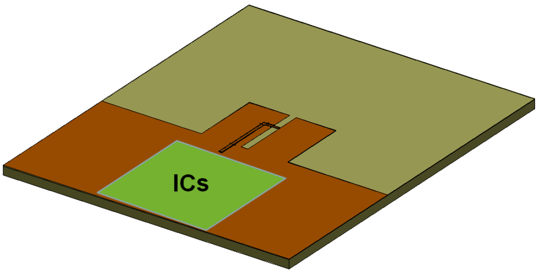
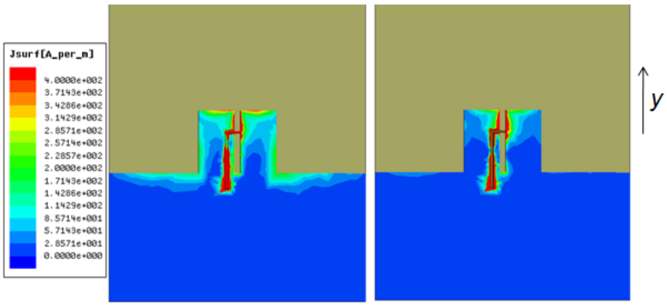


Fig.9 ICs modelization by a metal ground plane just behind antenna



(a) (b)

Fig.10 Illustration of surface current distribution on the entire structure: at 57 GHz (a) and at 77 GHz (b).

The surface currents are essentially localized on the top of twin tail fins and at 57 GHz, the upper edge of the ground plane is also exploited. But, at any frequencies, no surface current is present on the antenna backside. Furthermore, the main radiation in the substrate plane (+*y* direction) allows a good isolation between antenna radiation and active circuits.

V. Conclusion

A broadband antenna on HR SOI CMOS technology for mmWave co-integration has been described with associated matching and radiation performances. One interest of the proposed antenna is its capacity on the excitation type (TFMS and CPW) obtaining a wide impedance range. The interest of co-integration is to match directly the antenna with the output – respectively the input – impedance of the PA – respectively the LNA.

The proposed antenna presents an ultra wide band characteristic with a good radiation efficiency and performance stability over the frequency band. The simulated bandwidth (VSWR=2) is greater than 30 GHz. The simulated gain is greater than 5 dBi and the co-/cross-polarization ratio is above 20 dB on the entire bandwidth. So, the antenna achieves very high radiation performances and respects the 60 GHz specifications targeted for mmWave WLAN systems. The other advantage is the flexibility in terms of feeding structures with two excitation types (TFMS and CPW) available. This flexibility associated with its design simplicity is well suited in a co-integration context. Indeed, the twin tail fins antenna is a good solution in order to propose mmWave low cost SoC and can be implemented for higher frequency applications such as medical imaging at 94, 140 or 220 GHz.

Acknowledgements

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